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(54) **SYSTEMS AND METHODS FOR A POLARIZATION MATCHED RESONATOR FIBER OPTIC GYROSCOPE**

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USPC 356/460, 461, 464
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(57) **ABSTRACT**

Systems and methods for a polarization matched resonator fiber optic gyroscope are provided. In one embodiment an RFOG comprises: a light source; a fiber optic ring resonator; a photodetector that outputs an electrical signal that varies as a function of optical intensity; and an input light polarization servo. A light beam from the servo is launched into the resonator ring in a first direction of circulation. The input polarization servo comprises a birefringence modulator that modulates a phase shift between two components of an input polarization state of the light beam at ω_m, the modulator is controlled to drive towards zero a 1^{st} harmonic of ω_m as measured in the electrical signal. The servo further comprises a tunable ½ waveplate that adjusts an amplitude of the two components of the input polarization state relative to each other. The tunable ½ waveplate is controlled to maximize a peak optical intensity as measured in the electrical signal.

20 Claims, 2 Drawing Sheets

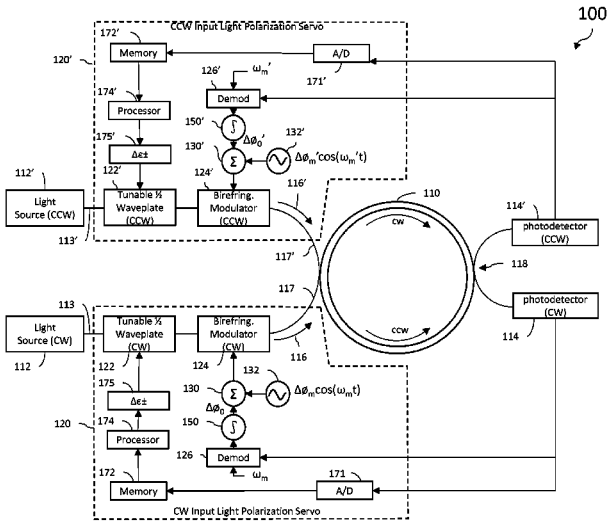

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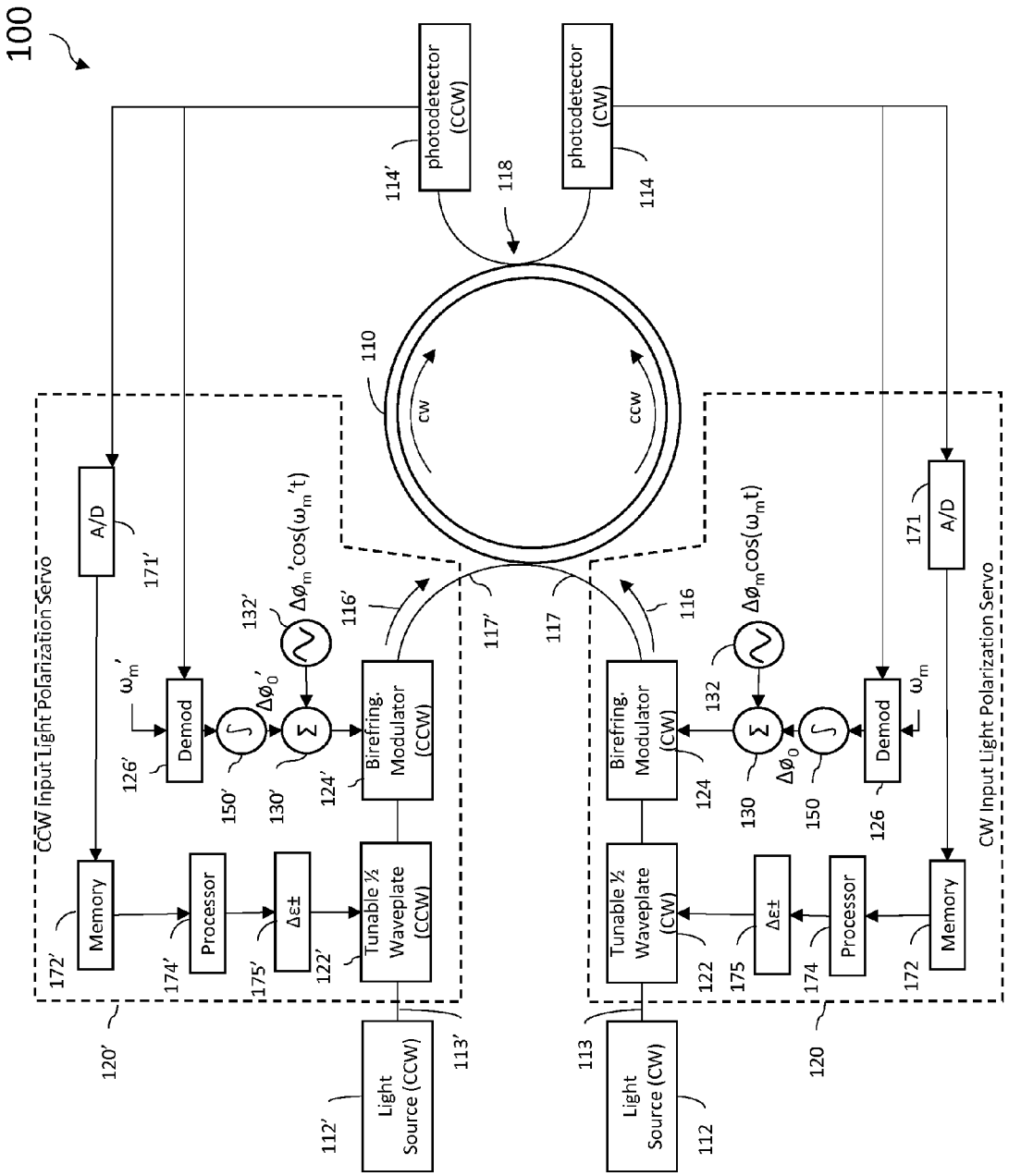
Fig. 1


100
photodetector (CCW)
photodetector (CW)
114'
114
118
110
cw
ccw
CCW Input Light Polarization Servo
CW Input Light Polarization Servo
A/D
Demod
Memory
Processor
Δε±
Tunable ½ Waveplate (CCW)
Tunable ½ Waveplate (CW)
Birefring. Modulator (CCW)
Birefring. Modulator (CW)
Light Source (CCW)
Light Source (CW)
ω_m'
ω_m
$\Delta\phi_0'$
$\Delta\phi_0$
$\Delta\phi_m'\cos(\omega_m' t)$
$\Delta\phi_m\cos(\omega_m t)$
171'
171
172'
172
174'
174
175'
175
122'
122
124'
124
126'
126
130'
130
132'
132
150'
150
116'
116
117'
117
113'
113
112'
112
120'
120

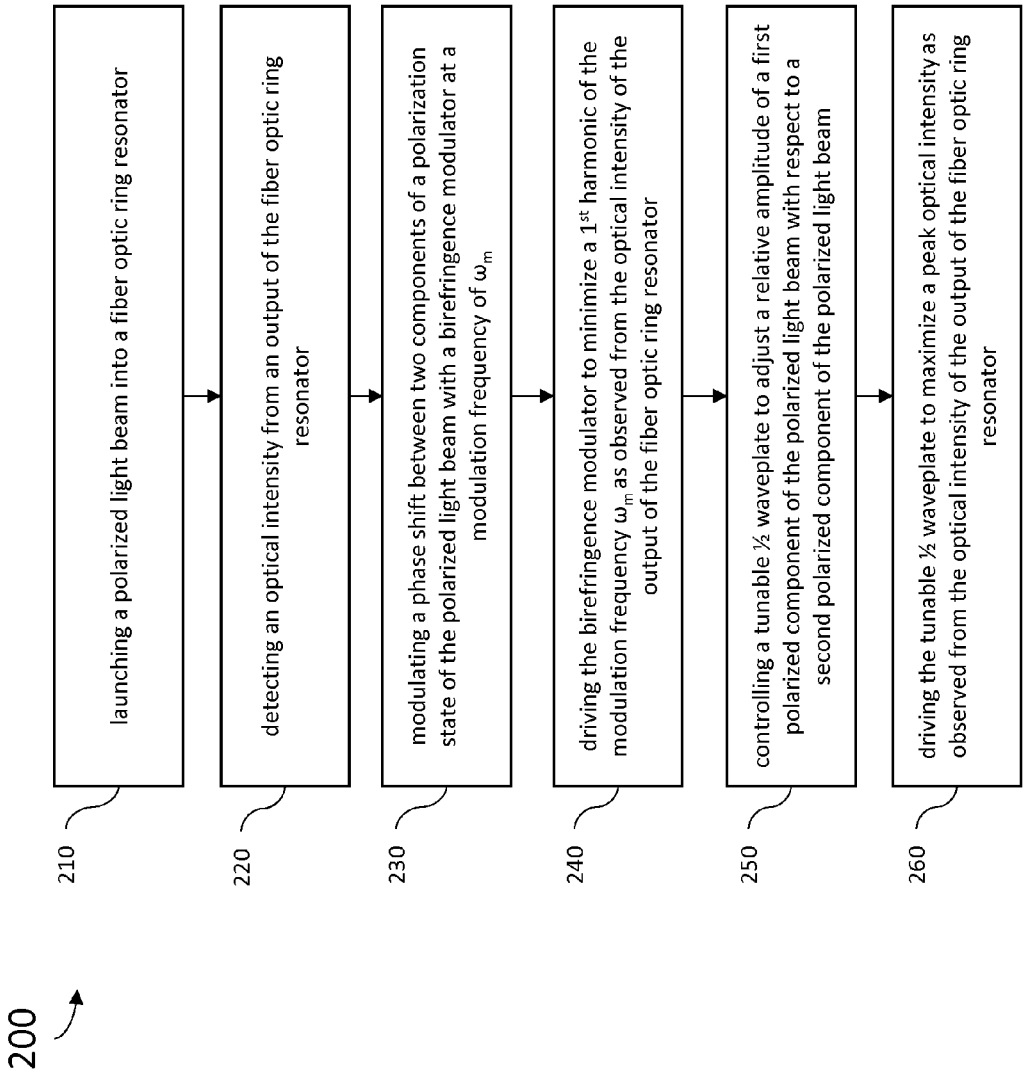

200
210
launching a polarized light beam into a fiber optic ring resonator
220
detecting an optical intensity from an output of the fiber optic ring resonator
230
modulating a phase shift between two components of a polarization state of the polarized light beam with a birefringence modulator at a modulation frequency of ω_m
240
driving the birefringence modulator to minimize a 1st harmonic of the modulation frequency ω_m as observed from the optical intensity of the output of the fiber optic ring resonator
250
controlling a tunable ½ waveplate to adjust a relative amplitude of a first polarized component of the polarized light beam with respect to a second polarized component of the polarized light beam
260
driving the tunable ½ waveplate to maximize a peak optical intensity as observed from the optical intensity of the output of the fiber optic ring resonator

Fig. 2

SYSTEMS AND METHODS FOR A POLARIZATION MATCHED RESONATOR FIBER OPTIC GYROSCOPE

BACKGROUND

In commercial navigation application, there is a continuing need for developing low cost, small sized navigation grade gyroscopes. The resonator fiber optic gyro (RFOG) is one gyroscope technology that can satisfy those needs. In the RFOG, a ring resonator is formed using a fiber optic coil and couplers to couple light into and out of the ring resonator in clockwise (cw) and counterclockwise (ccw) directions. At least two input light waves are frequency-tuned to the resonances of the ring resonator in the cw and ccw directions respectively. After measuring the resonance frequencies in the two directions by tuning each input beam to them, the input beam frequencies are compared, and the difference is proportional to the rotation rate of the resonator coil. In an RFOG bias instability is manifested as an indicated rotation rate output even when the gyroscope is not rotating.

For the reasons stated above and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the specification, there is a need in the art for improved systems and methods to address RFOG bias instability.

SUMMARY

The embodiments of the present invention provide methods and systems for polarization matched resonator fiber optic gyroscope and will be understood by reading and studying the following specification.

In one embodiment, a polarization matched resonator fiber optic gyroscope (RFOG) comprises: a first light source; a fiber optic ring resonator coupled to the first light source; a first photodetector coupled to an output of the fiber optic ring resonator, where the first photodetector outputs an electrical signal that varies as a function of optical intensity measured by the first photodetector; and a first input light polarization servo; wherein the fiber optic ring resonator is coupled to the first light source via the first input light polarization servo such that a light beam from the first input light polarization servo is launched into the fiber optic resonator ring in a first direction of circulation; wherein the first input polarization servo comprises a birefringence modulator that modulates a phase shift between two components of the input polarization state of the light beam at a modulating frequency ω_m, wherein the birefringence modulator is further controlled to drive towards zero a 1^{st} harmonic of the modulating frequency ω_m as measured in the electrical signal; wherein the first input polarization servo further comprises a tunable ½ waveplate that adjusts an amplitude of the two components on the input polarization state relative to each other, wherein the tunable ½ waveplate is controlled to maximize a peak optical intensity as measured in the electrical signal.

DRAWINGS

Embodiments of the present invention can be more easily understood and further advantages and uses thereof more readily apparent, when considered in view of the description of the preferred embodiments and the following figures in which:

FIG. **1** is a block diagram illustrating a polarization matched resonator fiber optic gyroscope of one embodiment of the present disclosure; and

FIG. **2** is a flow chart illustrating a method of one embodiment of the present disclosure.

In accordance with common practice, the various described features are not drawn to scale but are drawn to emphasize features relevant to the present invention. Reference characters denote like elements throughout figures and text.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of specific illustrative embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that logical, mechanical and electrical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense.

One of the major causes of bias instability in RFOGs originates from the polarization of light that propagates within the gyroscope's ring resonator used to measure rotation. Errors in the indicated rotation rate of an RFOG can be caused by imperfect overlap of the input polarization states of light in the cw and ccw directions with the resonant polarization state of the fiber ring resonator. When the polarization state of the input light waves in each direction are matched with the resonator polarization state, errors due to polarization behavior in the RFOG can be greatly reduced or eliminated altogether.

One issue with achieving this matched condition is that there is polarization cross-coupling within the input beams paths to the resonator that keeps it from being in the exact desired polarization state at the input to the resonator. The existence of this cross-coupling in the input leads, as well as thermally induced fluctuations in the birefringence of the input leads, can cause the input light wave polarization state to fluctuate over time, causing the coupling of input light into the polarization state of the resonator to vary. The magnitude of the cross-coupling itself can vary over time. Furthermore, even if the input light state were completely stable at the entrance of the resonator, the polarization state inside the resonator at its input can vary over time, causing the overlap with the input polarization state to vary.

The various embodiments described herein provide systems and methods for very accurately launching the input light into one polarization mode within the ring resonator reducing bias instability within the RFOG. As described in detail below, one or more of these embodiments use active feedback to constantly adjust the input polarization state of the cw and ccw inputs beams to track and match the desired polarization state of the ring resonator.

FIG. **1** is a flow chart illustrating a polarization matched resonator fiber optic gyroscope (RFOG) **100** of one embodiment of the present invention. RFOG **100** comprises a fiber optic resonator ring **110** coupled to a first light source **112** via a first input light polarization servo **120**. Light waves (shown at **116**) exit from input light polarization servo **120** through input leads **117** and are launched into the resonator ring **110** where they circulate around the ring **110** in a clockwise (CW) direction. A fraction of the circulating CW light waves can be coupled out of resonator ring **110** (shown at **118**) and detected by photodetector **114**.

For simplicity, only components related to the CW operation of RFOG **100** are discussed in detail below. However, as

shown in FIG. **1**, RFOG **100** does comprise symmetrical set of counterclockwise components. That is, fiber optic resonator ring **110** is also coupled to a second light source **112'** via a second input light polarization servo **120'**. Light waves (shown at **116'**) exit from input light polarization servo **120'** into an input lead **117'** and are launched into the resonator ring **110**. This light beam circulate around the ring **110** in a counter-clockwise (CCW) direction. A fraction of the circulating CCW light waves are coupled out of resonator ring **110** and detected by photodetector **114'**. Primed (') reference indicators (i.e., x') are used to indicate elements relevant to CCW operation. Each of the primed components (e.g., **113'**, **116'**, **117'**, **122'**, **124'**, **126'**, **130'**, **132'**, **150'**, **171'**, **172'**, **174'** and **175'**) associated with input light polarization servo **120'** can be assumed to be functionally identical as those described for their like-named non-primed counterparts (**113**, **116**, **117**, **122**, **124**, **126**, **130**, **132**, **150**, **171**, **172**, **174** and **175'** respectively) for input light polarization servo **120**, except that their operation is applicable to launching the CCW circulating light beam. In some embodiments, the first and second light sources **112**, **112'** may actually comprise a single light source whose output is split into two beams that are separately fed into the appropriate CW and CCW components. Further, the first and second light sources **112**, **112'** may be implemented, for example using tunable lasers that produce monochromatic light beams.

As shown in FIG. **1**, input light polarization servo **120** comprises a tunable ½ waveplate **122**, a birefringence modulator **124**, a first demodulator **126**, a second demodulator **128**, a summing amplifier **130** and a sinusoidal generator **132**. The eigenstate of polarization for resonator ring **110**, which will be referred to herein generally as the resonator polarization state, may be defined by two components X & Y and represented by the column matrix:

$$\binom{X}{Y}, \text{ where X and Y are complex.}$$

where X and Y are complex.

The light within resonator ring **110** is already highly (but not perfectly) polarized so that the amplitude of the Y component may be defined by ϵ (where ϵ is $<<1$) which is equal to the relative amplitude of the Y component as compared to the amplitude of the X component. Thus the resonator polarization state may be represented by the normalized matrix:

$$b\begin{pmatrix} 1 \\ \epsilon e^{i\varphi} \end{pmatrix},$$

where

$$b = \sqrt{\frac{1}{1+\epsilon^2}}$$

and ϕ is the phase difference between the X and Y components.

The light **113** entering input light polarization servo **120** is also already polarized into a similar polarization state, but the polarization state of light beam **113** will be mismatched with respect to the resonator polarization state. That is, ϵ for the polarization state of light **113** is off by $\Delta\epsilon$, while ϕ is off by $\Delta\phi$. The polarization state of light **113** entering input light polarization servo **120** can therefore be characterized by the normalized matrix:

$$a\begin{pmatrix} 1 \\ (\epsilon-\Delta\epsilon)e^{i(\varphi-\Delta\varphi)} \end{pmatrix}, \text{ where } a = \sqrt{\frac{1}{1+(\epsilon-\Delta\epsilon)^2}}$$

Thus if input light polarization servo **120** is operated to drive both $\Delta\epsilon$ E and $\Delta\phi$ of light beam **113** to zero, the polarization state of the launch light **116** will have the same polarization state as exists inside ring resonator **110**.

To address $\Delta\phi$, input light polarization servo **120** comprises a birefringence modulator **124** positioned within the path of the light beam **113** prior to the ring resonator **110**. Birefringence modulator **124** modulates the phase difference between the X-component and the Y-component of the launch light **116** (which is referred to herein as the input polarization state). There are various means for implementing birefringence modulator **124**. For example, in one embodiment birefringence modulator **124** comprises a lithium niobate electro-optic phase modulator positioned along a principal axis of the input fiber **117** (which may comprise a length of polarization maintaining fiber). In another embodiment, an electro-optic transparent ceramic material is used, such as those manufactured at Boston Applied Technologies Incorporated (BATI).

In the example embodiment shown in FIG. **1**, a voltage is applied to birefringence modulator **124** which controls birefringence modulator **124** and the modulation of the phase shift between the x-component and the y-component of the input polarization state of launch light **116**. The voltage driving birefringence modulator **124** is actually the sum of two voltage components, which may be added together by a summing amplifier **130**. The first voltage component, produced by a sinusoid generator **132** (which can comprise an oscillator or similar device), is characterized by the time varying function $\Delta\varnothing_m \cos(\omega_m t)$, where $\Delta\varnothing_m$ is a selected amplitude and ω_m is the modulation frequency. The second voltage component. $\Delta\varnothing_0$ is derived from a feedback signal provided by photodetector **114**. The value of $\Delta\varnothing_0$ is a function of the $\Delta\phi$ difference. As discussed above, a ring resonator's eigenstate of polarization at its input can change over time and with changes in temperature. Observing the overlap between the resonator polarization state and the input state from the output of the ring resonator (as opposed to attempting to estimate a polarization state upstream from the ring resonator output) is believed to provide the best representation of the overlap, between input light polarization state and the resonator's true polarization state. The overlap between input state and the resonator state is a measure of the fraction of light energy from the input light wave is coupled into the resonator polarization state when the input frequency of light is adjusted to the resonance frequency of the resonator polarization state. The closer the fraction of light energy is to unity, the more perfect the overlap, which is the intent of this invention.

More specifically, the output intensity variation from ring resonator **110** at the peak of the resonance is sensed at ω_m. It would be appreciated that signal processing methods known in the art may be used to control the cw and ccw input wave frequencies to the resonances centers of the cw and ccw resonances, respectively. Optical intensity observed by photodetector **114** is converted into an electrical signal which is fed into the first demodulator **126**. The first demodulator **126** is also referred to herein as the 1^{st} harmonic demodulator, because it demodulates the electrical signal from photodetector at the modulation frequency ω_m. The output of the first demodulator **126** is a DC voltage or digital value proportional to $\Delta\phi$. The output of the first demodulator drives an integrator **150**. In one embodiment, integrator **150** comprises a digital

accumulator. The integrator **150** output ramps up in response to a non-zero output of the first demodulator **126**, which results, in steady state, in a DC voltage component $\Delta\varnothing_0$ that is imparted to the birefringence modulator **124** to adjust $\Delta\phi$ such that $\Delta\phi=0$. If the input polarization state misalignment angle $\Delta\phi$ is equal to 0 originally, the output of the first demodulator is zero and the input to the integrator **150** is zero. Thus, the integrator **150** output is zero in steady state. If there is a change in $\Delta\phi$, such that $\Delta\phi\neq0$, then there exists a phase difference between the X-component and the Y-component of the input polarization state of launch light **116** that is different than that of the resonator polarization state. Therefore, birefringence modulator **124** is driven to minimize changes in intensity (i.e., minimize AO at the phase modulation frequency ω_m so that a phase difference between the X and Y components is applied. In this case, when $\Delta\phi\neq0$, in the detected output of the photodetector **114** at ω_m will be temporarily non-zero, the demodulated output of demodulator **126** will be temporarily non-zero, and the integrator **150** output will adjust the value of $\Delta\varnothing_0$ until steady state is reached. In steady state, the $\Delta\phi=0$, and therefore the detected signal at ω_m will be zero, as well as the demodulated output of the first demodulator. When $\Delta\varnothing_0$ is adjusted such that $\Delta\phi$ is driven to zero, variation at ω_m will vanish, indicating that the phase shift ϕ for the input polarization state of launch light **116** and the phase shift ϕ for the resonator polarization state match and $\Delta\phi$ has been driven to zero or minimized.

As mentioned above, input light polarization servo **120** is operated to drive both $\Delta\epsilon$ and $\Delta\phi$ of light beam **113** to zero. To ensure maximum matching of the input polarization state to the resonator polarization state, the relative amplitudes of the x-component and the y-component of the input polarization state may be adjusted to drive $\Delta\epsilon$ towards zero. To minimize $\Delta\epsilon$, input light polarization servo **120** also comprises a tunable ½ waveplate **122** positioned within the path of the light beam **113** prior to the ring resonator **110**.

In the example embodiment shown in FIG. **1**, a driving voltage may be applied to tunable ½ waveplate **122** which causes tunable ½ waveplate **122** to rotate its optical axis, thus affecting the relative amplitudes of the X-component and the Y-component of launch light **116**. It would be appreciated that a ½ waveplate typically operates to take linear light and rotate the plane of linear polarization of that light. In the present case, the input state is very near linear, but does comprise an X-component and Y-component. Here rotating the axis of the ½ waveplate operates to shift part of the X-component light to the Y-component, and part of the Y-component light to the X-component. In this way, the relative amplitudes of the X and Y components are altered by the ½ waveplate **122**.

This driving voltage that controls tunable ½ waveplate is derived from a feedback signal responsive the peak optical intensity of light received at photodetector **114**. Optical intensity observed by photodetector **114** is sampled and converted into an electrical signal which is fed into a sampling analog-to-digital converter **171** within the input light polarization servo **120**. The output of photodetector **114** as a function of time will comprise a DC component with a sinusoidal ripple riding on the DC component due to the application of modulation frequency ω_m by modulator **124**. Input light polarization servo **120** is configured to capture the maximum optical intensity level observed during each cycle of modulation frequency ω_m and average that maximum optical intensity level over time to arrive at what is referred to herein as the peak optical intensity. Averaging the measured maximum optical intensity levels over time provides the benefit of averaging out random noise sources that may cause spikes observed during individual cycles.

More specifically, analog-to-digital converter (A/D) **171** generates optical intensity sample data that is stored in memory **172**. Samples are captured and stored at a sufficient frequency to capture details such as the waveform peak of the electrical signal. For example, in one embodiment, samples of the electrical signal are obtained at a rate of 1000× per cycle of the modulation frequency ω_m. Memory **172** stores sample data covering a sufficient number of cycles so that averaging the cycles of sample data stored in memory **172** effectively averages out random noise captured during individual cycles. For example, in some embodiments, memory **172** stores between 10 to 100 cycles of sample data. Alternately, in other embodiments, memory **172** may store an average of previously captured cycles and a weighted average is performed with data samples for the most recently captured cycle or cycles. The averaging of sample data stored in memory **172** is performed by processor **174** in order to arrive at the value of the peak optical intensity. Processor **172** further drives tunable ½ waveplate **122** via a waveplate controller **175** to maximize the peak optical intensity of light received at photodetector **114**. That is, waveplate controller **175** produces the driving voltage that controls tunable ½ waveplate **122** based on a control signal from processor **172**. Maximizing peak optical intensity of light received at photodetector **114** results in driving $\Delta\epsilon$ to zero.

In one embodiment, processor **172** maximizes peak optical intensity by observing the effects adjusting tunable ½ waveplate **122** has on the observed peak optical intensity. For example, if rotating the axis of tunable ½ waveplate **122** in one direction produces an increase in peak optical intensity, then peak optical intensity prior to the adjustment was not maximized. When a control point is found such that rotating the plane of linear polarization in either direction from that control point will produce a decrease in peak optical intensity, then peak optical intensity at that control point is maximized.

In one embodiment the 1^{st} feedback loop used for controlling $\Delta\phi$ is operated at higher bandwidth than the 2^{nd} feedback loop used for controlling $\Delta\epsilon$. Keeping the two loops separated in frequency space can be utilized to avoid conflicts between them. For example, in one embodiment where the 1^{st} harmonic feedback loop operates with 100 Hz bandwidth, the 2^{nd} harmonic feedback loop operates with 1-10 Hz since variations in phase error may be expected to occur at a greater frequency that variations in the relative amplitude error.

As explained above, the two major variables in the input polarization state of launch light **116**, the polarization components' relative phase and amplitude, are adjusted to match that of the resonator polarization state of ring resonator **110**. By controlling these variables in the launch light to match the resonator eigenstate, maximum power is coupled into the ring resonator **110** for maximum signal to noise, bias instabilities associated with interference from excitation of the second eignestate of the resonator are minimized or eliminated, and intensity fluctuations inside the resonator that give rise to optical Kerr effect variations (another bias instability mechanism) may be minimized.

FIG. **2** is a flow chart that illustrates a method **200** on one embodiment of the present disclosure for operating a polarization matched resonator fiber optic gyroscope. In one embodiment, the method **200** is performed using the elements shown in FIG. **1**. In other embodiments, other elements may be utilized. Accordingly, any features, alternatives and optional implementations described with respect to FIG. **1** would be applicable to the method **200** of FIG. **2** and viseverse. Further, method **200** describes a process that may be applied to either the cw or ccw operation of an RFOG. Therefore, an RFOG configured to utilize method **200** can be

expected to simultaneously perform two independent instances of method **200**, one implemented with respect to the cw circulation of light in the ring resonator, one implemented with respect to the ccw circulation of light in the ring resonator.

The method begins at **210** with launching a polarized light beam into a fiber optic ring resonator. The polarized light may originate from a light source, such as a tunable laser that produce monochromatic light beams. The method continues to **220** with detecting an optical intensity from an output of the fiber optic ring resonator. Observing the signal from the output of the ring resonator is believed to provide the best representation of how well the input light polarization state is matched to the resonator's true polarization state. The method proceeds to **230** with modulating a phase shift between two components of the polarization state of the polarized light beam with a birefringence modulator at a modulation frequency of ω_m. In one embodiment, the birefringence modulator is driven by a voltage having two components. The first component is characterized by the time varying function $\Delta\phi_m \cos(\omega_m t)$, where $\Delta\phi_m$ is a selected amplitude and ω_m is the modulation frequency. The second voltage component is the DC offset voltage, $\Delta\phi_0$ derived from a feedback signal derived from the optical intensity measurements obtained in block **220**. Accordingly, the method proceeds to **240** with driving the birefringence modulator to minimize a 1^{st} harmonic of the modulation frequency ω_m as observed from the optical intensity of the output of the fiber optic ring resonator. As discussed above in FIG. **1**, in one embodiment, the electrical signal produced by a photodetector measuring the optical intensity of the output of the fiber optic ring resonator can be demodulated at the modulation frequency ω_m in order to observe the 1^{st} harmonic. Minimizing this first harmonic will drive $\Delta\phi$ to zero, matching the phase angle between components of the launched light input polarization state to that of the resonator polarization state.

The method proceeds to **250** with controlling a tunable ½ waveplate to adjust a relative amplitude of a first polarized component of the polarized light beam with respect to a second polarized component of the polarized light beam. To ensure maximum matching of the input polarization state to the resonator polarization state, the relative amplitudes of the x-component and the y-component of the input polarization state can be adjusted to drive $\Delta\epsilon$ to zero. In the example embodiment shown in FIG. **1**, a voltage is applied to tunable ½ waveplate **122** which causes tunable ½ waveplate **122** to rotate its optical axis, affecting the relative amplitudes of the X-component and the Y-components of launch light **116**. Accordingly the method proceeds to **260** with driving the tunable ½ waveplate to maximize a peak optical intensity as observed from the output of the fiber optic ring resonator. In one embodiment, the optical intensity observed at block **220** is converted into an electrical signal which is sampled and stored in a memory. A processor may then determine a peak optical intensity, which can be calculated by averaging or otherwise statistically analyzing data samples captured over a plurality of modulating frequency ω_m cycles. A non-maximized peak optical intensity evidenced by observing the output of the ring resonator indicates that the relative amplitudes of the input polarization state components of launch light do not match those of the resonator polarization state. Accordingly, the tunable ½ waveplate at block **260** is therefore driven to generate feedback that drives the fiber optic resonator ring **110** to maximize peak optical intensity, which results in driving $\Delta\epsilon$ to zero.

Example Embodiments

Example 1 includes a polarization matched resonator fiber optic gyroscope (RFOG), the gyroscope comprising: a first light source; a fiber optic ring resonator coupled to the first light source; a first photodetector coupled to an output of the fiber optic ring resonator, where the first photodetector outputs an electrical signal that varies as a function of optical intensity measured by the first photodetector; and a first input light polarization servo, wherein the fiber optic ring resonator is coupled to the first light source via the first input light polarization servo such that a light beam from the first input light polarization servo is launched into the fiber optic resonator ring in a first direction of circulation; wherein the first input polarization servo comprises a birefringence modulator that modulates a phase shift between two components of an input polarization state of the light beam at a modulating frequency ω_m, wherein the birefringence modulator is further controlled to drive towards zero a 1^{st} harmonic of the modulating frequency ω_m as measured in the electrical signal; and wherein the first input polarization servo further comprises a tunable ½ waveplate that adjusts an amplitude of the two components of the input polarization state relative to each other, wherein the tunable ½ waveplate is controlled to maximize a peak optical intensity as measured in the electrical signal.

Example 2 includes the gyroscope of example 1, further comprising: a second light source coupled to the fiber optic ring resonator; a second photodetector coupled to a second output of the fiber optic ring resonator, where the second photodetector outputs a second electrical signal that varies as a function of optical intensity measured by the second photodetector; and a second input light polarization servo; wherein the fiber optic ring resonator is coupled to the second light source via the second input light polarization servo such that a second light beam from the second input light polarization servo is launched into the fiber optic resonator ring in a second direction of circulation opposite from the first direction of circulation; wherein the second input polarization servo comprises a second birefringence modulator that modulates a second phase shift between two components of an input polarization state of the second light beam at a second modulating frequency ω_{m2}, wherein the second birefringence modulator is further controlled to drive towards zero a 1^{st} harmonic of the second modulating frequency ω_{m2} as measured in the second electrical signal; and wherein the second input polarization servo further comprises a second tunable ½ waveplate that adjusts an amplitude of the two components of the input polarization state of the second light beam relative to each other, wherein the second tunable ½ waveplate is controlled to maximize a peak optical intensity as measured in the second electrical signal.

Example 3 includes the gyroscope of any of examples 1-2, the first input polarization servo further comprising: a sinusoid generator that outputs a first voltage component characterized by the time varying function $\Delta\phi_m \cos(\omega_m t)$, where $\Delta\phi_m$ is a selected amplitude and ω_m is the modulation frequency; and a 1^{st} harmonic demodulator coupled to the first photodetector, wherein the 1^{st} harmonic demodulator demodulates the electrical signal from first photodetector at the modulation frequency ω_m; and an integrator that outputs a second voltage component $\Delta\phi_0$ from an output of the 1^{st} harmonic demodulator; wherein the phase shift between the two components of the input polarization state of the light beam applied by the birefringence modulator is controlled by a summation of the first voltage component with the second voltage component.

Example 4 includes the gyroscope of any of examples 1-3, wherein the second voltage component drives the birefringence modulator to minimize $\Delta\phi$.

Example 5 includes the gyroscope of any of examples 1-4, further comprising a summing amplifier that combines the first voltage component with the second voltage component.

Example 6 includes the gyroscope of any of examples 1-5, wherein the birefringence modulator comprises either: a lithium niobate electro-optic phase modulator, or an electro-optic transparent ceramic material.

Example 7 includes the gyroscope of any of examples 1-6, first input polarization servo further comprising: a processor that calculates the peak optical intensity from digital samples of the electrical signal from the first photodetector; and a waveplate controller responsive to the processor, where based on the peak optical intensity, the processor outputs a control signal instructing the waveplate controller to output a driving voltage applied to the tunable ½ waveplate; wherein the tunable ½ waveplate adjusts the amplitude of the two components of the input polarization state relative to each other based on the driving voltage.

Example 8 includes an input light polarization servo for a resonator fiber optic gyroscope (RFOG) comprising a ring resonator, a light source providing a polarized light beam, and a photodetector coupled to an output of the ring resonator, the servo comprising: a birefringence modulator configured to modulate a phase shift between two components of an input polarization state of the polarized light beam, where the birefringence modulator modulates the phase shift with a modulation frequency ω_m, wherein the birefringence modulator is further configured to modulate the phase shift to minimize a 1^{st} harmonic of the modulation frequency ω_m as detected by the photodetector from the output of the ring resonator; and a tunable ½ waveplate that adjusts a relative amplitude of the two components of the input polarization state, wherein the tunable ½ waveplate is configured to maximize a peak optical intensity as detected by the photodetector from the output of the ring resonator.

Example 9 includes the servo of example 8, further comprising: a sinusoid generator coupled to the birefringence modulator, where the sinusoid generator outputs a sinusoidal voltage having the modulation frequency ω_m, wherein the sinusoidal voltage is applied to the birefringence modulator to modulate the phase shift at the modulation frequency ω_m; a 1^{st} harmonic demodulator coupled to the photodetector; and an integrator coupled to the 1^{st} harmonic demodulator; wherein the 1^{st} harmonic demodulator demodulates an electrical signal from the photodetector at the modulation frequency ω_m to produce an output to the integrator; wherein the integrator outputs a second voltage component $\Delta\phi_0$, wherein the second voltage component $\Delta\phi_0$ is applied to the birefringence modulator to further modulate the phase shift; and where the birefringence modulator is controlled by feedback from the second voltage component to drive the 1^{st} harmonic of the modulation frequency ω_m as detected from the electrical signal to a minimum.

Example 10 includes the servo of any of examples 8-9, further comprising a summing amplifier that combines the sinusoidal voltage with the second voltage component.

Example 11 includes the servo of any of examples 8-10, wherein the second voltage component drives the birefringence modulator to minimize $\Delta\phi$.

Example 12 includes the servo of any of examples 8-11, further comprising: a processor that calculates the peak optical intensity from digital samples of the electrical signal from the photodetector; and a waveplate controller responsive to the processor, where based on the peak optical intensity, the processor outputs a control signal instructing the waveplate controller to output a driving voltage; wherein the tunable ½ waveplate is controlled by feedback from the driving voltage to drive the peak optical intensity as detected from the electrical signal to a maximum.

Example 13 includes the servo of any of examples 8-12, wherein the birefringence modulator comprises either: a lithium niobate electro-optic phase modulator, or an electro-optic transparent ceramic material.

Example 14 includes a method for matching an input polarization state of launch light to a resonator polarization state of a resonator fiber optic gyroscope, the method comprising: launching a polarized light beam into a fiber optic ring resonator; detecting an optical intensity from an output of the fiber optic ring resonator; modulating a phase shift between two components of a polarization state of the polarized light beam with a birefringence modulator at a modulation frequency of ω_m; driving the birefringence modulator to minimize a 1^{st} harmonic of the modulation frequency ω_m as observed from the optical intensity of the output of the fiber optic ring resonator; controlling a tunable ½ waveplate to adjust a relative amplitude of a first polarized component of the polarized light beam with respect to a second polarized component of the polarized light beam; and driving the tunable ½ waveplate to maximize a peak optical intensity as observed from the optical intensity of the output of the fiber optic ring resonator.

Example 15 includes the method of example 14, wherein launching the polarized light beam further comprises: producing a monochromatic light beam from a laser.

Example 16 includes the method of any of examples 14-15, wherein detecting the optical intensity from the output of the fiber optic ring resonator further comprises: measuring the optical intensity of the fiber optic ring resonator with a photodetector coupled to an output of the fiber optic ring resonator, where the photodetector outputs an electrical signal that varies as a function of optical intensity measured by the photodetector

Example 17 includes the method of any of examples 14-16, wherein driving the birefringence modulator to minimize a 1^{st} harmonic of the modulation frequency ω_m as observed from the optical intensity of the output of the fiber optic ring resonator further comprises: demodulating the electrical signal from the photodetector at the modulation frequency ω_m; and adjusting the phase shift between the two components of the polarization state to drive to a minimum the 1^{st} harmonic of the modulation frequency ω_m as detected from the demodulating.

Example 18 includes the method of any of examples 14-17, wherein driving the tunable ½ waveplate to maximize the peak optical intensity as observed from the optical intensity of the output of the fiber optic ring resonator further comprises: calculating the peak optical intensity from digital samples of the electrical signal; and controlling the tunable ½ waveplate to adjust an amplitude of the two components of the input polarization state relative to each other based on the peak optical intensity.

Example 19 includes the method of any of examples 14-18, wherein controlling a tunable ½ waveplate to adjust the relative amplitude of the first polarized component of the polarized light beam with respect to the second polarized component of the polarized light beam further comprises: rotating an optical axis of the tunable ½ waveplate.

Example 20 includes the method of any of examples 14-19, wherein modulating a phase shift between two components of the polarization state of the polarized light beam with a birefringence modulator at the modulation frequency of ω_m further comprises: driving the birefringence modulator with a voltage signal characterized by $\Delta\phi_m \cos(\omega_m t)$, where $\Delta\phi_m$ is a selected amplitude and ω_m is the modulation frequency.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement, which is calculated to achieve the same purpose, may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present invention. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.

What is claimed is:

1. A polarization matched resonator fiber optic gyroscope (RFOG), the gyroscope comprising:

a first light source;

a fiber optic ring resonator coupled to the first light source;

a first photodetector coupled to an output of the fiber optic ring resonator, where the first photodetector outputs an electrical signal that varies as a function of optical intensity measured by the first photodetector; and

a first input light polarization servo;

wherein the fiber optic ring resonator is coupled to the first light source via the first input light polarization servo such that a light beam from the first input light polarization servo is launched into the fiber optic resonator ring in a first direction of circulation;

wherein the first input polarization servo comprises a birefringence modulator that modulates a phase shift between two components of an input polarization state of the light beam at a modulating frequency ω_m, wherein the birefringence modulator is further controlled to drive towards zero a 1^{st} harmonic of the modulating frequency ω_m as measured in the electrical signal; and

wherein the first input polarization servo further comprises a tunable ½ waveplate that adjusts an amplitude of the two components of the input polarization state relative to each other, wherein the tunable ½ waveplate is controlled to maximize a peak optical intensity as measured in the electrical signal.

2. The gyroscope of claim **1**, further comprising:

a second light source coupled to the fiber optic ring resonator;

a second photodetector coupled to a second output of the fiber optic ring resonator, where the second photodetector outputs a second electrical signal that varies as a function of optical intensity measured by the second photodetector; and

a second input light polarization servo;

wherein the fiber optic ring resonator is coupled to the second light source via the second input light polarization servo such that a second light beam from the second input light polarization servo is launched into the fiber optic resonator ring in a second direction of circulation opposite from the first direction of circulation;

wherein the second input polarization servo comprises a second birefringence modulator that modulates a second phase shift between two components of an input polarization state of the second light beam at a second modulating frequency ω_{m2}, wherein the second birefringence modulator is further controlled to drive towards zero a 1^{st} harmonic of the second modulating frequency ω as measured in the second electrical signal; and

wherein the second input polarization servo further comprises a second tunable ½ waveplate that adjusts an amplitude of the two components of the input polarization state of the second light beam relative to each other, wherein the second tunable ½ waveplate is controlled to maximize a peak optical intensity as measured in the second electrical signal.

3. The gyroscope of claim **1**, the first input polarization servo further comprising:

a sinusoid generator that outputs a first voltage component characterized by the time varying function $\Delta\phi_m \cos(\omega_m t)$, where $\Delta\phi_m$ is a selected amplitude and ω_m is the modulation frequency;

a 1^{st} harmonic demodulator coupled to the first photodetector, wherein the 1^{st} harmonic demodulator demodulates the electrical signal from first photodetector at the modulation frequency ω_m; and

an integrator that outputs a second voltage component $\Delta\phi_0$ from an output of the 1^{st} harmonic demodulator;

wherein the phase shift between the two components of the input polarization state of the light beam applied by the birefringence modulator is controlled by a summation of the first voltage component with the second voltage component.

4. The gyroscope of claim **3**, wherein the second voltage component drives the birefringence modulator to minimize $\Delta\phi$.

5. The gyroscope of claim **3**, further comprising a summing amplifier that combines the first voltage component with the second voltage component.

6. The gyroscope of claim **3**, wherein the birefringence modulator comprises either:

a lithium niobate electro-optic phase modulator, or

an electro-optic transparent ceramic material.

7. The gyroscope of claim **1**, first input polarization servo further comprising:

a processor that calculates the peak optical intensity from digital samples of the electrical signal from the first photodetector; and

a waveplate controller responsive to the processor, where based on the peak optical intensity, the processor outputs a control signal instructing the waveplate controller to output a driving voltage applied to the tunable ½ waveplate;

wherein the tunable ½ waveplate adjusts the amplitude of the two components of the input polarization state relative to each other based on the driving voltage.

8. An input light polarization servo for a resonator fiber optic gyroscope (RFOG) comprising a ring resonator, a light source providing a polarized light beam, and a photodetector coupled to an output of the ring resonator, the servo comprising:

a birefringence modulator configured to modulate a phase shift between two components of an input polarization state of the polarized light beam, where the birefringence modulator modulates the phase shift with a modulation frequency ω_m, wherein the birefringence modulator is further configured to modulate the phase shift to minimize a 1^{st} harmonic of the modulation frequency ω_m as detected by the photodetector from the output of the ring resonator; and

a tunable ½ waveplate that rotates a plane of linear polarization of the polarized light beam to adjust a relative amplitude of the two components of the input polarization state, wherein the tunable ½ waveplate is configured to maximize a peak optical intensity as detected by the photodetector from the output of the ring resonator.

9. The servo of claim **8**, further comprising:

a sinusoid generator coupled to the birefringence modulator, where the sinusoid generator outputs a sinusoidal voltage having the modulation frequency ω_m, wherein the sinusoidal voltage is applied to the birefringence modulator to modulate the phase shift at the modulation frequency ω_m;

a 1^{st} harmonic demodulator coupled to the photodetector; and

an integrator coupled to the 1^{st} harmonic demodulator;

wherein the 1^{st} harmonic demodulator demodulates an electrical signal from the photodetector at the modulation frequency ω_m to produce an output to the integrator;

wherein the integrator outputs a second voltage component $\Delta\phi_0$, wherein the second voltage component $\Delta\phi_0$ is applied to the birefringence modulator to further modulate the phase shift; and

where the birefringence modulator is controlled by feedback from the second voltage component to drive the 1^{st} harmonic of the modulation frequency ω_m as detected from the electrical signal to a minimum.

10. The servo of claim **9**, further comprising a summing amplifier that combines the sinusoidal voltage with the second voltage component.

11. The servo of claim **9**, wherein the second voltage component drives the birefringence modulator to minimize $\Delta\phi_0$.

12. The servo of claim **8**, further comprising:

a processor that calculates the peak optical intensity from digital samples of the electrical signal from the photodetector; and

a waveplate controller responsive to the processor, where based on the peak optical intensity, the processor outputs a control signal instructing the waveplate controller to output a driving voltage;

wherein the tunable ½ waveplate is controlled by feedback from the driving voltage to drive the peak optical intensity as detected from the electrical signal to a maximum.

13. The servo of claim **8**, wherein the birefringence modulator comprises either:

a lithium niobate electro-optic phase modulator, or

an electro-optic transparent ceramic material.

14. A method for matching an input polarization state of launch light to a resonator polarization state of a resonator fiber optic gyroscope, the method comprising:

launching a polarized light beam into a fiber optic ring resonator;

detecting an optical intensity from an output of the fiber optic ring resonator;

modulating a phase shift between two components of a polarization state of the polarized light beam with a birefringence modulator at a modulation frequency of ω_m;

driving the birefringence modulator to minimize a 1^{st} harmonic of the modulation frequency ω_m as observed from the optical intensity of the output of the fiber optic ring resonator;

controlling a tunable ½ waveplate to adjust a relative amplitude of a first polarized component of the polarized light beam with respect to a second polarized component of the polarized light beam; and

driving the tunable ½ waveplate to maximize a peak optical intensity as observed from the optical intensity of the output of the fiber optic ring resonator.

15. The method of claim **14**, wherein launching the polarized light beam further comprises:

producing a monochromatic light beam from a laser.

16. The method of claim **14**, wherein detecting the optical intensity from the output of the fiber optic ring resonator further comprises:

measuring the optical intensity of the fiber optic ring resonator with a photodetector coupled to an output of the fiber optic ring resonator, where the photodetector outputs an electrical signal that varies as a function of optical intensity measured by the photodetector.

17. The method of claim **16**, wherein driving the birefringence modulator to minimize a 1^{st} harmonic of the modulation frequency ω_m as observed from the optical intensity of the output of the fiber optic ring resonator further comprises:

demodulating the electrical signal from the photodetector at the modulation frequency ω_m; and

adjusting the phase shift between the two components of the polarization state to drive to a minimum the 1^{st} harmonic of the modulation frequency ω_m as detected from the demodulating.

18. The method of claim **16**, wherein driving the tunable ½ waveplate to maximize the peak optical intensity as observed from the optical intensity of the output of the fiber optic ring resonator further comprises:

calculating the peak optical intensity from digital samples of the electrical signal; and

controlling the tunable ½ waveplate to adjust an amplitude of the two components of the input polarization state relative to each other based on the peak optical intensity.

19. The method of claim **14**, wherein controlling a tunable ½ waveplate to adjust the relative amplitude of the first polarized component of the polarized light beam with respect to the second polarized component of the polarized light beam further comprises:

rotating an optical axis of the tunable ½ waveplate.

20. The method of claim **14**, wherein modulating a phase shift between the two components of the polarization state of the polarized light beam with a birefringence modulator at the modulation frequency of ω_m further comprises:

driving the birefringence modulator with a voltage signal characterized by $\Delta\phi_m \cos(\omega_m t)$, where $\Delta\phi_m$ is a selected amplitude and ω_m is the modulation frequency.

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